Examination and Comparison of TOSCA Orchestration Tools

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Abstract. The use of orchestration and automation has been growing in recent years. This can be especially evident in cloud infrastructures where OASIS TOSCA orchestration standard can be used to provide independence and prevent vendor lock-in. In this paper we examine different TOSCA compliant orchestration tools, test them with TOSCA templates and present a comparison between these tools. This comparison should be used to decide which tool is easier to use for both the companies and the developers according to their requirements.

Keywords: Comparison · Cloud Computing · DevOps · Orchestration · Automation · Orchestrator · Orchestration tool · TOSCA.

1 Introduction

Automation and orchestration tools usually do not draw the attention of developers who are independent or are working on smaller projects. However, for large companies and corporations they are of great significance, bringing business value through the possibilities to orchestrate and transfer applications throughout several cloud infrastructures. Although developers want complete independence from the target platforms, numerous cloud providers only provide compatibility and first–party support for their own services. This can create a significant impact on the effort and cost expenditure, associated with the migration of services to from one to another cloud platform. Companies therefore search for universal orchestration tools, which promise compatibility with many cloud providers. However, these often don't support specific functionalities within each of the supported cloud platforms. To pick the orchestrator and the accompanying tools means researching their advantages and also all their drawbacks. There currently seems to be no evident intersection between orchestration or automation support within the cloud services as orchestrators usually do not support deployment on all available cloud platforms and also do not support all possible automation tools. For this paper we delve into orchestration and set a goal to examine and compare different orchestration tools in order to make the decision process more straightforward. This paper presents the properties and use of several selected tools.

1.1 DevOps and Orchestration

Development and Operations (DevOps for short) is an approach in information technology that emphasizes communication and integration between software developers and other IT experts and is used mostly for introducing automated software and infrastructure changes [7].

Orchestration is a sort of distributed automated configuration that includes monitoring and coordination of computer systems, application and services and thereby helps making the execution of complex tasks or task groups easier. The process of orchestration is used to solve the problem of connecting and arranging larger amounts of automated tasks in a desired workflow [14]. Within orchestration a workflow is defined (this is usually called a process of workflow orchestration) and consists of a sequence of automated tasks. Based on the orchestration targets there are many different types of orchestration and the ones that stand out the most are cloud orchestration, service orchestration and release orchestration [8].

It is important to distinguish orchestration from automation which are often confused. The execution of a task and the operations within, belongs to the automation, which aims to reduce the human factor in the processes that can be automated. On the other hand, the orchestration process aims to join the majority of already automated tasks and put them in a logical order which then results in the deployment of the complete application or services[3].

1.2 Orchestration tools

Orchestrators or orchestration tools represent a wide set of complex IT software that is used to invoke the aforementioned process of workflow orchestration. These tools can be very specific – from deploying applications to setting up Docker containers. In order to pick the appropriate tool we should follow different criteria such as:

- the size of the company which is important when paying for tool licences,
- the operating systems used in the orchestrated system,
- whether the tool is open-source or commercial, where one should note that open-source tools are often supported by their community and that commercial tools offer professional support and can therefore be used in mission–critical IT systems [13].

The orchestration tools can often be scaled and can deliver highly complex applications and, as we repeat the tasks again and again, they become predictable and can be optimized. Apart from that, it is known that these tools reduce costs and errors (through repeatability of the orchestration process), increase productivity, save significant amount of time, make operations faster, minimize system down times etc. In the last few years there has been an enormous growth in cloud orchestration for several cloud providers (for instance Amazon Web Services, Microsoft Azure and Google Cloud Platform) where the orchestration

process includes deploying applications, creating cloud resources (e.g. for storage), configuring networks, setting up virtual machines and so on. Organizations use orchestrators to migrate their applications to the cloud and in doing so they increase the accessibility, reduce times for healing the services in case of errors and make all their business processes faster [15].

1.3 OASIS TOSCA standard

OASIS Topology and Orchestration Specification for Cloud Applications, or shortly TOSCA, is an open standard that defines the application topology within cloud infrastructures by dividing services into components and defining their connections, dependencies, capabilities and requirements. This makes the applications portable and independent of any cloud providers which corresponds to the DevOps theory of installing and delivering applications throughout their life cycle [11]. Apart from TOSCA there are other cloud orchestration standards such as Amazon AWS CloudFormation or OpenStack Heat, but they are specific and tailored to their platforms. CloudFormation seems to be more AWS oriented and Heat was designed for OpenStack and targets cloud workloads, whereas TOSCA is more general and meant for enterprise workloads and applications.

The TOSCA standard includes a special metamodel with a declarative domain-specific language that offers the definition of portable TOSCA documents called TOSCA templates and complete application packages (commonly called blueprints) which include templates with all the accompanying files needed for the deployment. All these files usually get packed into compressed artifacts called Cloud Service Archives or CSARs. TOSCA has a strictly defined system of types which for example includes node types, relationship types, their properties, attributes, interfaces, requirements and so on. The TOSCA standard can be used within different markup languages and the most common ones are YAML and XML. We centered ourselves around TOSCA Simple Profile for YAML that currently has four different versions (v1.0, v1.1, v1.2 and v1.3) [2].

There are currently many emerging and promising tools using TOSCA such as Alien4Cloud, Apache AriaTosca, CELAR, Cloudify, DICER, Eclipse Winery, MSO4SC HPC, Indigo, ONAP, OPEN-O, OpenBaton, OpenStack, OpenTOSCA, Opera, RADON, SODALITE, OPNFV, Puccini, SeaClouds, TosKer, Ubicity and so on. Some of them are completely compatibile with the standard and some others have extended it and defined their own DSL. However, TOSCA YAML templates have little practical value without their implementations. To provide these, different automation tools can be used, such as Ansible, Chef, Puppet, Salt, Juju, Jenkins, Vagrant, Bash, Docker and Terraform. TOSCA orchestrators are focused on connecting these tools with parsed TOSCA definitions so that tasks can be executed [12].

2 Testing the orchestration tools

For the analysis we have chosen xOpera, Ystia Yorc, IndigoDC and Cloudify orchestrators which all support TOSCA standard definitions. For the testing part

we prepared a simple TOSCA template (see Figure 1) for creating a directory with an example file. The template uses the latest TOSCA YAML profile version 1.3 (for the orchestrators which did not support this version we have changed it to lower ones). Here we defined one simple node type called `hello_type` with one input (which is set to `"Hello from TOSCA!"` at the beginning of the orchestration) and two paths to operations for creating (deploying) and deleting (undeploying).

```
tosca_definitions_version: tosca_simple_yaml_1_3

node_types:
  hello_type:
    derived_from: tosca.nodes.SoftwareComponent
    interfaces:
      Standard:
        inputs:
          content:
            default: { get_input: content }
            type: string
        operations:
          create: playbooks/create.yml
          delete: playbooks/delete.yml

topology_template:
  inputs:
    content:
      type: string
      default: "Hello from TOSCA!"

  node_templates:
    my-workstation:
      type: tosca.nodes.Compute
      attributes:
        private_address: localhost
        public_address: localhost

    hello:
      type: hello_type
      requirements:
        - host: my-workstation
```

Fig. 1: TOSCA YAML template for testing.

For the operation actuators we used Ansible playbooks because Ansible is the easiest automation tool for setup and usage and also most of the TOSCA orchestrators prefer and support it. The example playbook we used for the `create`

TOSCA interface operation is shown in Figure 2. A similar playbook was used to implement `delete` TOSCA operation.

```
- hosts: all
  gather_facts: false
  tasks:
    - name: Create the new folder structure
      file:
        path: /tmp/opera-test/hello
        recurse: true
        state: directory

    - name: Create hello.txt and add content
      copy:
        dest: /tmp/opera-test/hello/hello.txt
        content: "{{ content }}"
```

Fig. 2: Ansible playbook for the TOSCA create operation.

2.1 xOpera

xOpera is a project that includes opera tool which is a lightweight open-source TOSCA orchestrator compatible with TOSCA Simple Profile in YAML v1.3 [17]. As primary developers of opera we follow the UNIX convention of a minimal tool that does only one thing (e.g. orchestration) and that one thing well instead of having a tool that can handle multiple tasks of different types. This orchestration tool uses Ansible to implement the TOSCA standard operations which means that operations like deploy and un-deploy run a set of actuators in the form of Ansible playbooks [4]. Opera is easily installed through a Python pip package that is available on PyPI (https://pypi.org/project/opera/). Opera only provides the client CLI interface so it can be used very quickly [17]. Our xOpera orchestration test where we used `opera deploy` and `opera undeploy` commands has been successful (see Figure 3).

2.2 Ystia Yorc and Alien4Cloud

Yorc is the High Performance Computing (HPC) TOSCA orchestrator which targets support for hybrid infrastructure applications such as Infrastructure as a Service (IaaS), HPC schedulers and Container as a service (CaaS). The important part of Yorc are the scaling of applications within TOSCA workflows [18]. Yorc has multiple set–up options. The usual way is to run its server on a remote virtual machine (such as an OpenStack VM) where we have to take care of the configuration of the server. This is also important if we want to properly

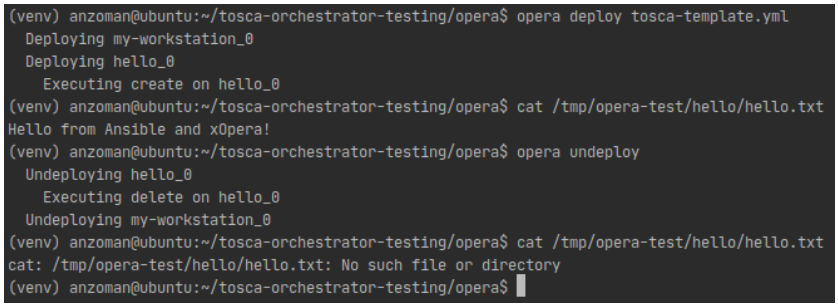

Fig. 3: The orchestration testing with xOpera.

interact with the open–source orchestration platform Alien4Cloud where Yorc is officially supported. An easier setup method that we used is to use the official Yorc Docker image and deploy the server in a Docker container. For interacting with the server we used a CLI client Yorc tool and downgraded the prepared TOSCA template to YAML version 1.2 which is the latest supported TOSCA version in Yorc. We also needed to pack our templates and playbooks in a zipped CSAR to be able to run the `yorc deployments deploy` command as shown in Figure 4.

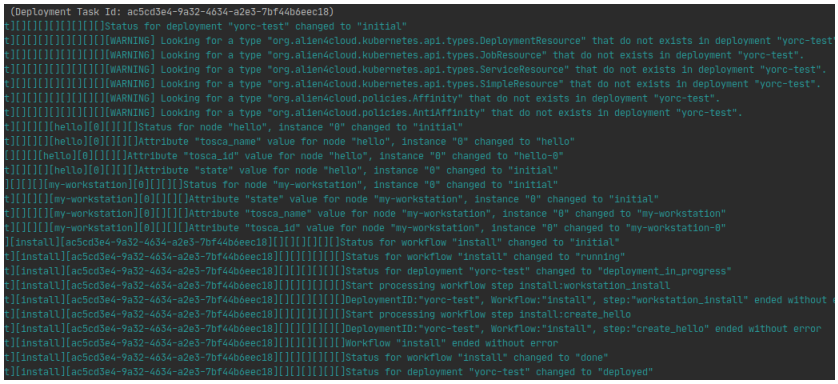

Fig. 4: Orchestration process result using Ystia Yorc.

Alien4Cloud (or a4c) stands for Application LIfecycle ENablement for Cloud or shorter Alien4Cloud which is an Atos open-source platform that facilitates managing complex applications and cloud services within companies and herewith also offers a tool for fast application deployment for users and developers. Alien4Cloud extends TOSCA Simple Profile in YAML along with all the TOSCA entities providing its DSL called Alien4Cloud DSL. The a4c orches-

trator receives a TOSCA CSAR artifact with all the TOSCA templates, their implementations and the accompanying files as an input. The orchestration process depends on the a4c version we use. Apart from officially supported Ystia Yorc there is also a support for Cloudify 3, Cloudify 4, experimental support for Marathon tool (which is a meta framework for Mesos offering orchestration of clusters and Docker containers) and the support for Puccini orchestration tool in beta version. By supporting multiple orchestrators Alien4Cloud becomes more independent from the cloud provider and therefore tries to prevent so called vendor lock-in since multiple orchestrator includes the support for multiple cloud providers. The installation of a4c can be done on Linux or OS X with one curl command in terminal solely and then we can already access the tool's dashboard in the browser. There is a simple drag and drop topology modelling tool where we can use already prepared a4c roles from the TOSCA topology catalog. TOSCA definitions can be imported from Git and when modelling is done we can export a full TOSCA template or CSAR. [1].

Because of numerous features that we found useful, we also decided to test the usage of a4c orchestration tool. After reshaping the TOSCA template to be compatible with Alien4Cloud domain specific language we have setup a4c platform in a Docker container and installed Yorc plugin to connect a4c with Yorc orchestrator. From there on the orchestration process was smooth as we packed our TOSCA templates into CSAR and initiated the deployment within the a4c platform.

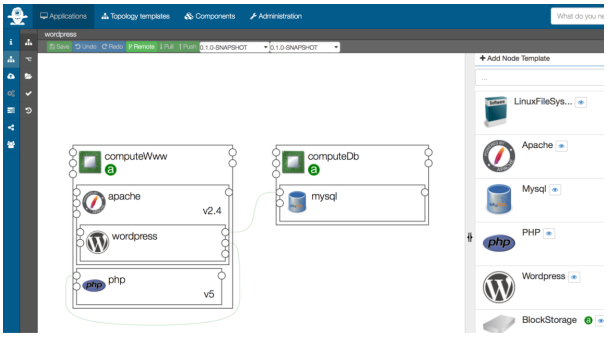

Fig. 5: Alien4Cloud topology modelling tool.

2.3 Indigo DC

IndigoDC is a TOSCA orchestration tool representing a Platform as a Service (PaaS) component which primarily offers setting up resources on cloud computing platforms like OpenStack or OpenNebula and also offers managing groups of computers using open–source Apache Mesos clusters [9]. The orchestrator

was developed within a European Union Horizon 2020 project called INDIGO-DataCloud (INtegrating Distributed data Infrastructures for Global ExplOitation) which aimed to provide hybrid infrastructure and software in the form of IaaS and SaaS components. The speciality of this tool is that it uses a Service License Agreement (SLA) to choose the orchestration target and the order of the automated tasks with the help of a REST service called Cloud Provider Ranker that collects the data about available cloud providers and chooses one using different rules and algorithms [16]. For the testing part we have set up Indigo DC server locally in a Docker container and used the Orchent CLI client tool to interact with the orchestrator. Indigo uses Ansible playbook or roles for TOSCA operations but the supported version of TOSCA YAML is only 1.0 so we had to refactor our TOSCA template by providing minor changes to TOSCA interface operation definitions. From that point we had issues as the orchestrator was unable to initiate the deployment. The problem was also that for the orchestrator to work we would have to supply different cloud provider secret credentials (like for AWS, Azure and GCP) to the server which could raise some security issues. The configuration if Indigo Data Cloud orchestrator was not intuitive so from there we did not proceed with the testing.

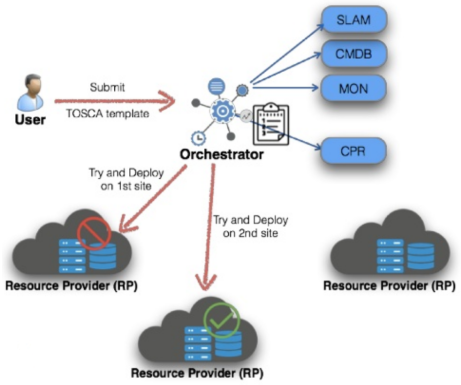

Fig. 6: Architecture of orchestration with IndigoDC [10]

2.4 Cloudify

Cloudify is an open-source framework for cloud orchestration with a built-in TOSCA orchestrator, modelling tool and monitoring software that offers modeling applications, optimizing their life cycle and deploying on numerous cloud providers [5]. Some of the components that can be a part of applications are included by default (for instance Nginx, Gunicorn, Flask, PostgreSQL, RabbitMQ and Pika), while others can be included through special plugins (for example

Ansible and cloud plugins). Cloudify can be used by setting up a Cloudify Manager in a Docker container that acts as an orchestration server and then it can be interacted with using the Cloudify CLI. The other way is to use the Cloudify web component that represents a concept of Environment as a Service (EaaS) to provide reusable orchestration environments with the goal to reduce the bottleneck between orchestration, automation, CI/CD tools and cloud providers. The Cloudify orchestrator has moved beyond TOSCA, developing its own Cloudify DSL that is used to define its own application blueprints. Therefore it offers Cloudify DSL versions 1.0, 1.1, 1.2 in 1.3 that are derived from corresponding TOSCA profiles. The DSL includes extended TOSCA definitions and plugins that can be used for TOSCA implementations (e.g. plugin defintions for Chef, Puppet, Ansible, Salt,...). The other embedded TOSCA actuators can be in the form of Python, Bash, PowerShell, Ruby scripts and so on [6].

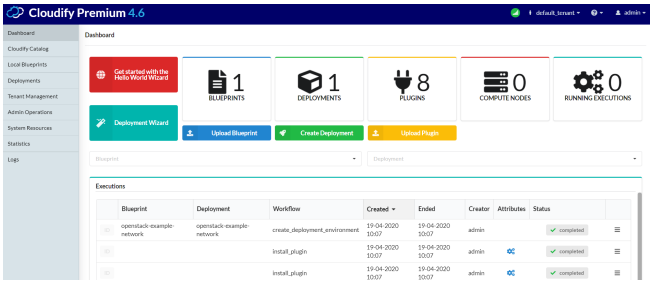

Fig. 7: Cludify dashboard.

For the testing part we used free testing license for Cloudify Labs (in Figure 7), translated our TOSCA template to Cloudify DSL and used the prepared Ansible playbooks for creating and deleting the service. We packed all the files into a CSAR and uploaded it to the Cloudify labs web portal where we initiated the workflow and the deployment (see Figure 8).

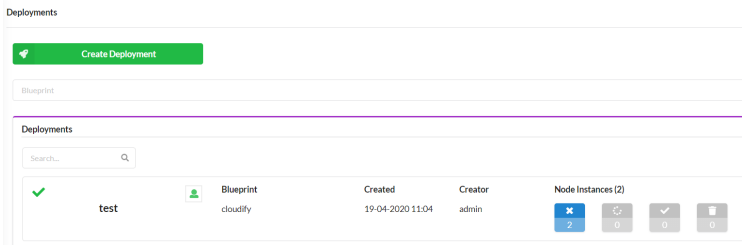

Fig. 8: Successful blueprint deployment via Cloudify Labs orchestrator.

3 The comparison of TOSCA orchestrators

During the testing of different orchestrators we created a comparison that would help us decide which tools are appropriate for the tested use case and to show the perspective that orchestrators have. The comparison is visible in Table 1 where we picked the most commonly occurring characteristics among these tools: release year, tool purpose, supported platforms, architecture, language, installation, license, supported automation tools, user interface, modeling tool, OASIS TOSCA compatibility, supported TOSCA profiles and supported cloud providers.

Aspect	Opera	Yorc	Indigo	Cloudify
Release year	2019	2017	2016	2012
Purpose	Minimalistic TOSCA orchestrator	HPC TOSCA orchestrator	TOSCA Paas orchestrator for cloud frameworks	Opensource TOSCA orchestration platform
Supported platforms	Linux, OS X, Windows	Linux	Linux	Linux, OS X
Architecture	client	server, client	server, client	server, client
Implemented in	Python	Go	Java	Python
Installation	Virtual environment and opera pip package	Server on an OpenStack VM or a Docker container	Server in a Docker container	Server on an OpenStack VM or a Docker container
Installation and usage difficulty	easy	medium	hard	medium
License	Apache License 2.0	Apache License 2.0	Apache License 2.0	Apache License 2.0
Supported automation tool	Ansible	Bash scripts, Ansible	Ansible	All (by default bash, Python, Ruby and other scripts and Ansible plugin
User interface	No	Yes	Yes	Yes
Modelling tool	No	Yes (Alien4Cloud)	No	Yes (embedded and Alien4Cloud)
TOSCA compatibility	Yes	Yes	Yes	No
Latest TOSCA profile version	TOSCA YAML 1.3	TOSCA YAML 1.2	TOSCA YAML 1.0, TOSCA NFV 1.0	Cloudify DSL 1.3 (derived from TOSCA 1.3)
Officially supported target cloud platforms	The support is performed by the user	AWS, OpenStack in GCP	AWS, Azure	AWS, Azure, GCP, OpenStack, vCloud(plugins)

Table 1: Orchestration tools comparison table.

Looking into the release year it is apparent that the newest orchestrator is xOpera and the oldest is Cloudify. Every tested orchestrator serves its own purpose such as: versatile and light-weight approach, supporting heterogeneous infrastructures (HPC, Cloud) for xOpera, HPC computing for Yorc, PaaS orchestrator for Indigo and open-source orchestration platform for Cloudify. All of the orchestrators support the Linux operating system and Cloudify has the additional support for OS X. Cloudify and xOpera are written in Python, Yistia Yorc in Go and IndigoDC is implemented in Java. All tools except xOpera require setting up an orchestration server which can reside in a Docker container. The installation process for xOpera consists of only installing it as a Python

package. Based on setup difficulty and usage we have categorized the xOpera orchestrator as easy to use, whereas Yorc and Cloudify were marked with medium difficulty. IndigoDC was the most problematic for usage because it consumed the biggest amount of time and at the end we were not able to use it for the orchestration. All analyzed orchestration tools have an open-source Apache 2.0 license. xOpera and Indigo are implementing the TOSCA standard by using Ansible as the automation tool, while Yorc offers Bash and Ansible. Cloudify is the most advanced in this aspect since it can be used with Python, Ruby or Bash scripts, with an embedded Ansible plugin or by using any other custom–defined plugin in order to use other automation tools like Chef, Puppet or Salt. Apart from xOpera, all of the tools provide a graphical user interface. Yorc and Cloudify also include a modelling tool for combining TOSCA entities and both are part of the Alien4Cloud platform. The orchestrators are fully compatible with TOSCA standard, except from Cloudify which uses its own DSL language, extending TOSCA standard definitions. Opera supports the latest TOSCA YAML profile version 1.3, Yorc supports YAML 1.2, Indigo used version 1.0 and also provides the support for TOSCA NFV network profile v1.0 and Cloudify also uses the latest TOSCA version since its DSL v1.3 is derived from TOSCA profile in YAML v1.3 but it also keeps the support for all the older TOSCA YAML versions. The xOpera orchestrator does not have any predefined cloud plugins and the user is required to provide the support himself based on TOSCA definitions and Ansible modules. Yorc explicitly supports OpenStack, AWS and GCP, whereas IndigoDC includes the support for AWS and Azure cloud providers. Cloudify can be connected to any cloud by using our custom plugins or the prepared plugins for AWS, Azure, GCP, OpenStack and VMware vCloud.

4 Results and decisions

The aspects of the orchestration tool comparison they helped us to decide which tool is the best for our testing use case. For us the most important characteristics were the installation, which had to be easy and fast. This allows us to test the deployment right away and consequently requires the latest TOSCA compatibility to keep up with the latest TOSCA standard features. Our key purpose, the minimalistic TOSCA orchestrator, which can be used for simple client deployment without any scaling or HPC features can be achieved by opera as the most suitable tool for our experiment. That choice might not be the best for other use cases. The presented comparison aspects can guide developers through the choice of the best tool according to their own different requirements. For instance if HPC computing is needed, uses should consider Yorc, as it was developed especially for that purpose, or maybe xOpera orchestrator if they want to benefit from the latest TOSCA version. For example if we would want to deploy our application on several cloud providers along with the use of various automation tools and plugins, Cloudify would prevail as it offers the support for almost all these tools. Then there are special cases when developers want to create a model of their application in a graphical environment with all the

visible connections between different components. Going this way opera is not the best choice, whereas Cloudify and Yorc along with Alien4Cloud modeling tool could stand out.

The next aspect that cannot be waved aside is the supported version of the TOSCA Simple Profile in YAML. Every version brings new syntax updates and features and it is important for the orchestrators to support the latest TOSCA versions in order to ensure the best possible cloud deployment process. There opera and Cloudify, which are based on latest TOSCA v1.3 are the most suitable. The security is also a big concern when picking these tools since engineers does not want to expose their cloud credentials (e.g. AWS secret keys, GCP service account keys etc.) to numerous possible treats and they want to be sure that the orchestrator or the service that is being used within will not copy or move credentials away from the local machine. Considering security, Cloudify seems as a good option as it provides so called secrets store which is a secure variable storage where the secrets are stored and called from as key-value pairs. On the other hand Yistia Yorc also turns out to be reliable in this perspective since it uses HashiCorp Vault to protect sensitive data. Apart from the fact that deployment with Indigo orchestrator did not work properly, this orchestrator has its own separated Identity and Access Management service which supports different cloud secrets and can be a good choice.

5 Conclusions and future work

Orchestration and with it, automation, are already important today, but will further gain importance, with the rise of 5G (and with it, edge). The latter will bring additional complexity basically on all infrastructure levels, as the number of connected devices and their capabilities will increase further. During our examination OASIS TOSCA turned out to be a promising standard with the ability to define and maintain application topology. Combined with orchestration tool and equipped with automation actuators TOSCA standard gets a practical use that can simplify multiple processes and can save a lot of precious time. All the orchestrators that we have tested were unique and had their own purpose whether this was HPC computing or PaaS interaction. Since we were not able to get IndigoDC to work, xOpera, Yorc and Cloudify were analyzed more in detail. Apart from Yorc being the official Alien4Cloud orchestrator, xOpera is also a tool with significant potential. From all the tools it was the easiest to install and to use. It does not have any embedded cloud plugins which is, in fact, not a negative thing since it then allows users to define this part as they wish. xOpera also supports the latest 1.3 version of TOSCA YAML which proves that the tool is being maintained and updated through time. Cloudify is a more enterprise solution and seems to be used by corporations which desire support and a user friendly environment, whereas xOpera is currently an open-source orchestrator in the making. This fact is also different from all the other tools, which seem to be in a mature state of development. It is evident that the orchestrator that will

be most flexible and will follow the latest cloud trends with the support for the latest TOSCA version will have a good chance of dominating.

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